The effect of annealing temperature on electrical properties of Pd/*n*-GaSb Schottky contacts

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Thermal stability for Pd/*n*-GaSb Schottky contacts is analyzed and studied. At room temperature, Pd/*n*-GaSb Schottky diodes have better performance, but when the annealing temperature is increased to 300 and 450 °C for 30 min, Schottky contacts gradually become ohmic contacts. From the measurement of Rutherford backscattering spectroscopy and x-ray diffraction analysis, the result indicates that the interdiffusion between palladium and gallium forming Ga_5Pd is the dominant factor for degrading properties of Schottky diodes.

I. INTRODUCTION

Currently, antimonide-based compound semiconductors lattice matched to GaSb substrates have generated considerable interest. The energy-band gaps not only cover a wide range, from 1.58 (AlGaSb) to 0.3 eV (InGaAsSb), but are also nearly equal to the spin-orbit splitting of the valence band Δ_0.[1,2] Sb-based alloy systems also become important materials due to their high electron mobilities. GaSb is a basic binary compound of the AlGaSb, InGaSb, and InGaAsSb compound semiconductors. InGaSb is a suitable material for microwave application due to its band structure in a particular range.[3] The narrow energy gap of InGaAsSb is also useful for long-wavelength photodevices.[4,5] With regard to AlGaSb, it is a promising material for an avalanche photodiode (APD) due to its high value of the ratio of β/α, where β and α are the hole and electron ionization coefficients,[6,7] respectively. Therefore, GaSb is a basic and important material for fabricating various devices. Schottky barrier photodiodes based on GaSb material have higher barrier height (0.6 eV) than the corresponding $In_xGa_{1-x}As$ material (0.15 and 0.2 eV) with the same band gap.[8,9] But less attention has been paid to them than *p*-*n* junction photodiodes.[10,11] Because of the advent of using high-power III-V devices, the need for high-reliability metallization technology becomes more crucial. Many transition metals are considered and investigated metallurgically as possible candidates for III-V Schottky barriers. To date, however, there has been less investigation on the post-annealing characteristics and thermal stability of metals/*n*-GaSb Schottky diodes than GaAs.[12]

In our recent research, we have found that palladium/*n*-GaSb Schottky diodes have better performance than other metals/*n*-GaSb Schottky diodes. Therefore, in this paper, *I*-*V* measurements were studied to evaluate the dependence of electrical properties of Pd/*n*-GaSb Schottky diodes on annealing temperature. Metallurgical characteristics of palladium film was studied by Rutherford backscattering spectroscopy (RBS) and x-ray diffraction (XRD). The reactivity of the Pd with GaSb substrates was used as a criterion for determining their thermal stability.

II. EXPERIMENT

The GaSb wafers used for the fabrication of Schottky diodes and interface transition study were *n* type (Te doped) with a doping concentration of about $2\text{–}6\times10^{17}$ cm^{-3}. Standard cleaning procedure including degreasing, etching, and HCl soaking was used just before loading into the evaporation chamber.[13] Rinsing in de-ionized water and exposing to the air were avoided in order to minimize the oxide formation on the surface. A standard photolithography and lift-off techniques were used for device patterns. The ohmic contacts of low resistance were formed by evaporating an Au-Ge-Ni eutectic mixture on the n^+ substrates back surfaces, followed by a temperature treatment at 300 °C for 5 min in a N_2 atmosphere. To form the Schottky barriers, palladium was then evaporated at 10^{-6} Torr about 5000 Å on the GaSb substrates at room temperature. After deposition, the samples were heat treated at 300 and 450 °C, respectively, for 30 min in N_2 atmosphere for studying the dependence of electrical properties of Pd/*n*-GaSb Schottky diodes on annealing temperature. The leads were connected to the contacts by using gold wires bonding. Current-voltage measurement was observed for electrical characteristics. Rutherford backscattering spectroscopy was used to analyze the interaction between Pd, GaSb, and thermal stability before and after temperature annealing. X-ray diffraction was also used to identify the crystal phases and the interaction compound.

III. RESULTS AND DISCUSSIONS

Figure 1 shows the current-voltage (*I*-*V*) characteristics for Pd/*n*-GaSb Schottky diodes at 27 °C, annealing at 300 and 450 °C for 30 min, respectively. The effect of annealing temperature on electrical properties can be clearly observed from Fig. 1. At room temperature, Pd/*n*-GaSb Schottky contacts had well-behaved forward and reverse characteristics (breakdown voltage is about 1.5 V). When

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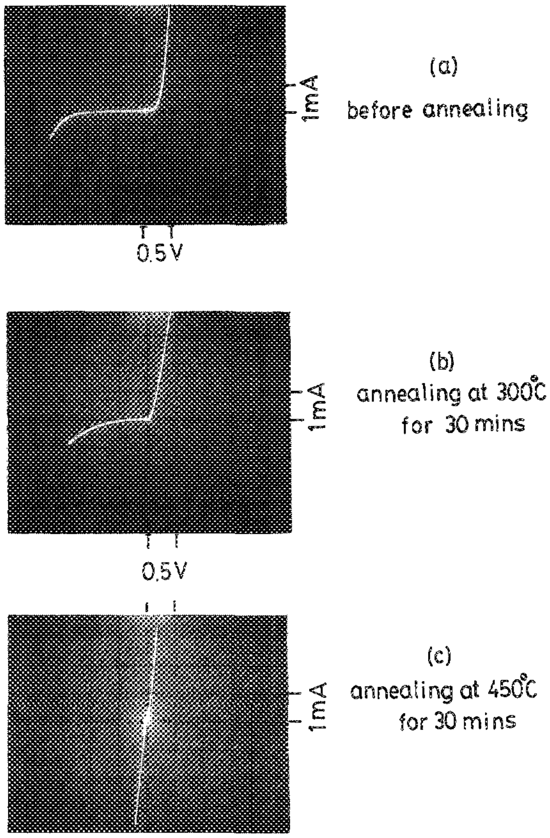

FIG. 1. Current-voltage characteristics of the Pd/n-GaSb Schottky diodes for different conditions: (a) good Schottky contacts before annealing, (b) lower breakdown voltage after annealing at 300 °C for 30 min, and (c) degraded Schottky barrier after annealing at 450 °C for 30 min.

the heat treatment temperature reaches 300 °C, the I-V characteristics are slightly like a resistor at forward bias and breakdown voltage is decreased to 1 V at the reverse bias. However, as the annealing temperature increased to 450 °C, Pd/n-GaSb contacts behaved as a 66-Ω resistor at both forward and reverse bias. This proved that Pd is easy to react with Ga or Sb to form complex compound in the interface, and it is hard to get better Schottky behavior at temperature higher than 300 °C as GaAs.[14] The interface transition between Pd and GaSb was studied and analyzed using Rutherford backscattering spectroscopy (RBS) with 2-MeV He^+ particles. Figure 2 showed the measured RBS spectra of Pd/n-GaSb contacts before and after 300 and 450 °C for 30-min heat-treatment annealing. There is an obvious Pd signal on the spectra before annealing, but it is difficult to get sharp transition Pd signal at channel number 660 in the RBS spectrum. This is due to similar atomic masses of Pd and Sb. As annealing temperature is increased to 300 °C for 30 min, the Pd signal is broaden, and it is somewhat difficult to distinguish the Pd signal from GaSb. For annealing at 450 °C for 30 min, it cannot be observed Pd signal at all. This fact indicates that Pd indiffusion and Ga and Sb outdiffusion appear at this higher temperature. In order to identify the crystal phase of the film before and after annealing, we use x-ray diffraction to analyze the interface transition. Figure 3 shows

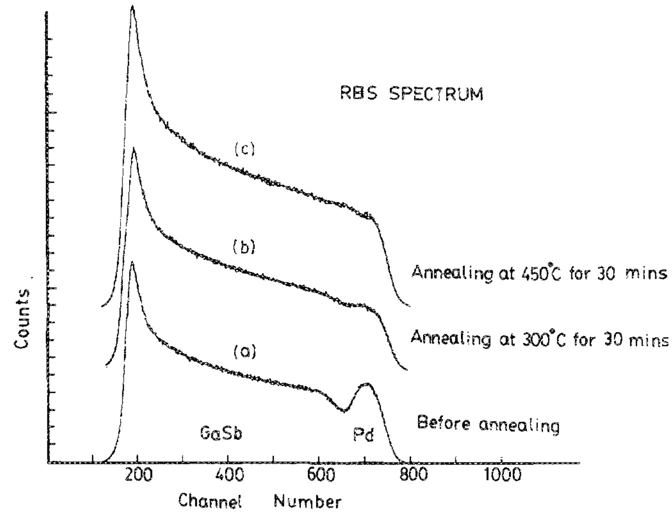

FIG. 2. The interface transition between Pd and GaSb is analyzed by Rutherford backscattering technique: (a) no interaction before annealing, (b) interaction occurred after annealing at 300 °C for 30 min, and (c) Pd signal disappeared after annealing at 450 °C for 30 min.

x-ray diffraction for 2θ from 30° to 70°. Before annealing, we can easily find Pd(111) and GaSb(400) peaks. This fact indicates that there is no interaction between Pd and GaSb. For annealing at 300 °C for 30 min, the Pd signal is slightly decreased and the Ga_5Pd signal is increased. When annealing up to 450 °C for 30 min, the Pd signal almost disappears, and $Ga_5Pd(220)$, $Pd_2Sb(115)$, $Ga_2Pd_5(420)$, and $Pd_8Sb_3(2110)$ signals are found. These facts point out that interaction between Pd and GaSb has occurred. Comparing with annealing at 300 °C, we can conclude that Ga_5Pd is the major factor for Pd/n-GaSb Schottky diodes forming a ohmic resistor.

IV. CONCLUSION

Although Pd/n-GaSb Schottky diodes have better electrical properties than other metals/n-GaSb Schottky diodes at room temperature, such as higher breakdown

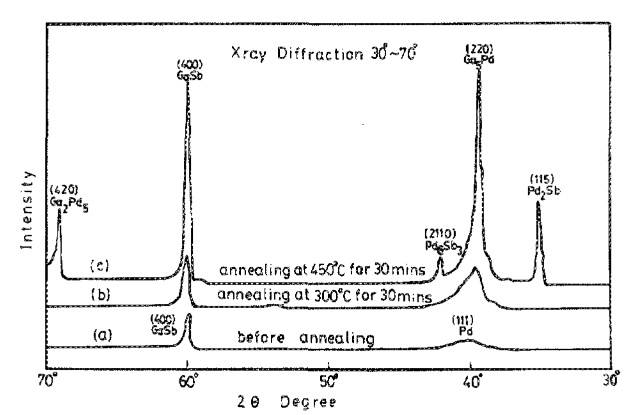

FIG. 3. X-ray diffraction pattern for 2θ from 30° to 70°: (a) only Pd(111) and GaSb(400) observed before annealing, (b) $Ga_5Pd(220)$ peak appeared after annealing at 300 °C for 30 min, and (c) $Ga_5Pd(220)$ peak intensity increased after annealing at 450 °C for 30 min.

voltage and good adhesive properties on GaSb, but the effect of temperature treatment will degrade the Schottky contact. From the RBS spectra and x-ray diffraction analysis, we can conclude that Pd indiffusion and Ga and Sb outdiffusion to form Ga_5Pd compound is very serious. This compound is the major reason for Pd/n-GaSb Schottky diodes forming a resistor at high temperature. The interaction between Pd and Ga is more dominant than Pd with Sb from x-ray diffraction analysis. Owing to the outdiffusion of Ga and Sb through the Pd layer during high temperature, the annealings cause the degradation of Schottky barriers. From above facts, the Pd/n-GaSb Schottky barrier cannot be operated in high-power operation.

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